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ABSTRACT

In this study, the development of pedagogical content knowledge (PCK) was explored within a group of 12 preservice teachers of chemistry (all M.Sc.) during their 1-year post-graduate teacher education program. The topic in this study concerned a central issue in science teaching, viz., the use of scientific models and modeling activities. A multiple-method approach was chosen. The collection of data involved (1) written responses to questionnaires and assignments; (2) audio recordings of workshop sessions; and (3) reflective reports, written by every individual preservice teacher. Results indicated a growth in preservice teachers' knowledge of students' difficulties in understanding models. Large differences were observed, however, between the preservice teachers with respect to their knowledge of teaching activities aimed at promoting students' understanding of models and modeling. The observed growth of PCK appeared to be influenced mostly by teaching experiences and by the workshops at the teacher education institute. In particular, the final workshop session during which the reflective reports of the individual teachers were discussed, had a major impact. (Contains 38 references.) (PVD)

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Investigating the development of preservice teachers' pedagogical content knowledge

Jan H. Van Driel (1) and Onno De Jong (2)

(1): ICLON Graduate School of Education, Leiden University, The Netherlands;

(2): Center for Science and Mathematics Education, Utrecht University, The Netherlands.

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National Association for Research in Science Teaching.

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All correspondence to:

J.H. van Driel

ICLON Graduate School of Education, Leiden University,

PO Box 9555

NL-2300 RB Leiden

The Netherlands

Phone: + 31 71 527 4027

Fax: + 31 71 527 5342

Email: Driel@ICLON.LeidenUniv.NL

J. van Driel

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Investigating the development of preservice teachers' pedagogical content knowledge

Abstract

In this study, the development of pedagogical content knowledge (PCK) was explored within a group of twelve preservice teachers of chemistry (all M.Sc.) during their one-year post-graduate teacher education program. The topic in this study concerned a central issue in science teaching, viz., the use of scientific models and modeling activities. A multiple-method approach was chosen. The collection of data involved (a) written responses to questionnaires and assignments, (b) audio recordings of workshop sessions, and (c) reflective reports, written by every individual preservice teacher. Results indicated a growth in preservice teachers' knowledge of students' difficulties in understanding models. Large differences were observed, however, between the preservice teachers with respect to their knowledge of teaching activities aimed at promoting students' understanding of models and modeling. The observed growth of PCK appeared to be influenced mostly by teaching experiences and by the workshops at the teacher education institute. In particular, the final workshop session during which the reflective reports of the individual teachers were discussed, had a major impact.

Introduction

In recent years, researchers have shown a growing interest in the knowledge base of preservice science teachers. Many studies have addressed fairly general aspects of teaching and learning science. For instance, researchers have investigated preservice teachers' conceptions of teaching and learning science (Brickhouse & Bodner, 1992; Mellado, 1998; Simmons et al., 1999) or their views on teaching science to students from various cultures (Southerland & Gess-Newsome, 1999), or the ways preservice teachers construct practical knowledge about teaching (Zuckerman, 1999). Other researchers have focused on the subject matter knowledge of preservice science teachers in the context of learning to teach (Gess-Newsome, 1999; Haidar, 1997). To acknowledge the importance of the transformation of subject matter knowledge per se into subject matter knowledge for teaching, Shulman introduced the concept of pedagogical content knowledge (PCK). He described PCK as "...that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (Shulman, 1987). Accordingly, PCK encompasses teachers' knowledge of representations and instructional strategies in relation to knowledge of student learning, both with respect to a specified content area.

In this study, the development of PCK was explored within a group of preservice teachers of chemistry. Moreover, we have tried to identify the influence of certain components of the preservice teacher education program (viz., specific workshops, student teaching experiences, and reflective reports, written by every individual preservice teacher) on this development. The purpose of the study was twofold. From a theoretical point of view, we aimed to gain a better understanding of factors which either promote or hinder the development of PCK (Grossman, 1990; Veal, 1998). Also, our study aimed to contribute to the research-based design of science teacher education courses.

Pedagogical content knowledge

According to Shulman, research on pedagogical content knowledge (PCK) may contribute to resolving the 'blind spot' which results from a relative lack of research focusing on the content of the lessons taught (Shulman, 1986). In the last decade, numerous studies on PCK have been published (e.g., Gess-Newsome & Lederman, 1999; Van Driel, Verloop & De Vos, 1998). Various scholars, elaborating on Shulman's work, have proposed different conceptualizations of PCK, in terms of the features they include or integrate (e.g., Cochran, DeRuiter, & King, 1993; Grossman, 1990; Magnusson, Krajcik & Borko, 1999; Marks, 1990; Veal, 1998). Yet it seems that that the two following elements are central in any conceptualization of PCK, that is, knowledge of representations of subject matter and instructional strategies incorporating these representations on the one hand, and understanding of specific student conceptions and learning difficulties on the other hand, both with respect to a specified content area. Obviously, these elements are intertwined and should be used in a flexible manner: the more representations and strategies teachers have at their disposal within a certain domain, and the better they understand their students' learning processes in the same domain, the more effectively they can teach in this domain. In addition, there appears to be agreement on the nature of PCK. First, since PCK refers to particular topics, it is to be discerned from knowledge of pedagogy, of educational purposes, and of learner characteristics in a general sense. Secondly, because PCK concerns the teaching of particular topics, it may turn out to differ considerably from subject matter knowledge per se. Finally, all scholars suggest that PCK is developed through an integrative process rooted in classroom practice, and that PCK guides the teachers' actions when dealing with subject matter in the classroom. The latter supports the view of Van Driel, Verloop and De Vos (1998) that PCK is a central

component of teachers' practical knowledge or craft knowledge (cf. Grimmett & MacKinnon, 1992).

Pedagogical content knowledge has been described as "the transformation of several types of knowledge for teaching" (Magnusson et al., 1999, p. 95). These types of knowledge include subject matter knowledge, pedagogical knowledge (classroom management, educational aims), and knowledge about context (school, students). Grossman (1990) has identified four sources that are potentially important with respect to the development of PCK: (a) disciplinary education, which may lead to personal preferences for specific educational purposes or topics, (b) observation of classes, both as a student and as a preservice teacher, often leading to tacit and, sometimes, conservative PCK, (c) classroom teaching experiences, and (d) specific courses or workshops during teacher education, of which the impact is normally unknown.

Within the domain of science teaching, several studies have been performed on the development of teachers' knowledge, in the context of both preservice and inservice teacher education. With respect to the development of PCK, the following results from these studies seem relevant:

- Knowledge of subject matter. According to Smith and Neale (1989), the development of PCK depends on teachers having a "deeply principled conceptual knowledge of the content." As for preservice teachers, the subject matter knowledge they have acquired during disciplinary education usually contains misconceptions and deficiencies (Smith, 1999). For instance, Gess-Newsome and Lederman (1993) found that the subject matter structures of preservice biology teachers, who had nearly completed the requirements for a BS in Science Education, was often vague and fragmented at the start of their teacher education program. During this program, the preservice teachers developed more

coherent and integrated subject matter structures. However, the development of PCK was hindered by the complexity of teaching practice.

- Teaching experience with respect to specific topics. According to Lederman et al. (1994), the development of PCK among preservice science teachers is promoted by the constant use of subject matter knowledge in teaching situations. Initially, preservice teachers separate subject matter knowledge from general pedagogical knowledge. As a result of teaching experiences however, these types of knowledge are being integrated.
- Knowledge of students' conceptions and learning difficulties. By getting acquainted with the specific conceptions and the ways students reason, preservice teachers may start to restructure their subject matter knowledge into a form that enables productive communication with their students (Lederman et al., 1994). In addition to field-based experiences, preservice teachers may benefit from studying students' preconceptions with respect to a specific topic during teacher education courses, and comparing and discussing these preconceptions in relation to their own conceptions (Geddis, 1993). Such activities may stimulate preservice teachers to generate transformations of subject matter knowledge and topic specific teaching strategies. Van Driel et al. (1998) have described the influence of inservice chemistry teachers' analyses of students' conceptions and types of reasoning concerning a specific topic (i.e., chemical equilibrium) on the development of their PCK of this topic.
- Participating in specific workshops. Clermont, Krajcik and Borko (1993) have studied the effects of a short, intensive workshop on specific teaching strategies (i.e., chemical demonstrations). They found that the PCK of preservice science teachers participating in this workshop developed towards that of expert teachers. On the other hand, Adams and Krockover (1997) found that workshops can have a negative effect because they can

stimulate preservice teachers to copy conventional instructional strategies, stressing procedures rather than student understanding.

Comparing these factors with the sources for PCK development described by Grossman, we may suggest that (a) disciplinary education, naturally, constitutes the basis for knowledge of subject matter, (b) observation of classes may promote the knowledge of students' conceptions, (c) classroom teaching experiences may stimulate the integration of subject matter knowledge and general pedagogical knowledge, thus contributing to the development of PCK, and (d) specific courses or workshops during teacher education have the potential to affect PCK, for instance, by extending preservice teachers' knowledge of students' preconceptions or their knowledge of specific representations of subject matter. The present study aims to improve our understanding of the nature of the development of PCK among preservice science teachers, in particular, the factors influencing this development.

Context and scope of the present study

The present study was situated in the context of a one-year post-graduate teacher education program, qualifying for the teaching of chemistry at pre-university level (cf., Grades 10-12 of secondary education). Before entering this program, participants need to have obtained a master's degree in chemistry. Generally speaking, the development of knowledge and beliefs during the program is seen as an individual process of knowledge construction. This process is guided by teaching experiences as a preservice teacher in a secondary school, supervised by a mentor, on the one hand, and by institutional meetings and workshops, and individual study of the literature on the other hand.

During the whole of the teacher education program, the preservice teachers work in schools. After a short period of observing and discussing their mentor's lessons, they begin to teach their own classes (about four to eight lessons per week). These classes are regularly observed by their mentors. During the program, the preservice teachers also take part in institutional meetings and workshops, for two afternoons per week on average. The main aim of these meetings and workshops is to stimulate the reflection on teaching experiences in relation to the relevant literature (e.g., on science education, pedagogy, educational psychology), as a result of which preservice teachers make their teaching concerns and intentions more explicit.

With respect to the development of PCK, the ideas from the previous section have been incorporated in the program as follows. Before they begin teaching a specific topic, the preservice teachers' subject matter knowledge of this topic is addressed by encouraging them to reflect on their own learning process as a student (Knowledge of subject matter). Next, during specific workshop sessions, they are asked to relate these reflections to their experiences during classroom lessons so far, and their study of the literature, in order to identify specific teaching and learning difficulties (Knowledge of students' conceptions and learning difficulties). Subsequently, the preservice teachers formulate teaching concerns, which then form the basis for their preparation of lesson plans focusing on the topic under consideration. After teaching these lessons (Teaching experience with respect to specific topics), the preservice teachers are asked to write reflective reports and formulate new teaching concerns (De Jong et al., 1999).

The present study focuses on the development of PCK about a central issue in chemistry teaching, that is, the use models and modeling in chemistry (cf. Van Driel & Verloop, 1999). Chemistry textbooks for secondary education contain many examples of scientific models, usually presenting these models as static facts. In spite of the current

emphasis on constructivist teaching strategies, these books only rarely include assignments inviting the students to actively construct, test, or revise models. Many scholars have conducted studies on the teaching and learning of the content of specific models, for instance, studies on corpuscular models, in which learning difficulties with respect to molecules and atoms are investigated (e.g., De Vos & Verdonk, 1987; Harrison & Treagust, 1996). Thus far, only a few scholars have focused on the process of modeling (Gilbert, 1991) and on students' conceptions of models and their use in science (Grosslight, Unger, Jay, & Smyth, 1991). Moreover, it is not clear which teaching activities concerning models and modeling are actually applied by science teachers, and for what reasons. It appears that, as yet, there have been no investigations of teachers' PCK in this domain.

It was decided to develop a new course module as a part of the teacher education program, with a specific focus on teaching models and modeling as a central element within chemistry education. This module was introduced about halfway the teacher education program, and was subsequently taught over a period of about 10 weeks. The first element of this module consisted of two series of questions addressing the preservice teachers' content knowledge and PCK with respect to models and modeling (see Appendices 1 and 2). The preservice teachers first answered the questions individually, after which their answers were discussed plenary during a workshop. The aim was to focus the attention of the preservice teachers on the subject of models and modeling by discussing their earlier experiences as a learner of chemistry (e.g. in secondary schools).

The next element of the module focused on some findings from the research literature. For this purpose the preservice teachers read a fragment of an article (Van Driel & Verloop, 1999, pp. 1142-1143), which identifies seven core characteristics of scientific models and modeling in science. In addition, the preservice teachers also read a selected section of another article (Grosslight et al., 1991, pp. 817-819), which describes three levels of

understanding of scientific models and their use in science, which were found with middle and high school students and experts. The preservice teachers were asked to respond to a series of questions which served to relate the content of the articles to the practice of chemistry education, that is, the way models are represented in textbooks and the understanding of models by students (see Appendix 3). In particular, the preservice teachers were asked to describe teaching activities they would want to use to bring their students from the lowest level of understanding (see Grosslight et al., 1991) to a higher level. During a workshop session, the articles were discussed. The discussion was organized on the basis of the questions in Appendix 3.

Some weeks later, a workshop was organized focusing on the development of intentions for teaching scientific models and modeling. For this purpose, the preservice teachers analyzed a chapter of a commonly used secondary school chemistry textbook for Grade 9 (*Chemie 3 havo/vwo*, 1995) dealing with characteristics of the models of atoms and molecules of Dalton. The preservice teachers first wrote down their expectations regarding the students' conceptual difficulties, as well as difficulties they expected to come across when teaching this chapter (see Appendix 4). Later during this workshop, they discussed their expectations and personal intentions with respect to teaching about models and modeling in their classrooms.

After this workshop, the preservice teachers chose a forthcoming topic from the chemistry curriculum in which specific models and/or modeling activities were dominantly present (see Appendix 5). The preservice teachers chose the following topics: characteristics of molecules in relation to macroscopic properties of substances and solutions (e.g., phase transitions, structures of alkanes and the alkanes' boiling points, cis-trans isomerism of alkenes, hydrogen bridges in relation to solubility and boiling points), the concept of the mole (specific number of particles corresponding to a certain mass of substance), meaning of

balancing reaction equations, rate of reaction and the model of collision of particles, galvanic cells (corpuscular explanations of phenomena). Each preservice teacher taught the chosen topic at his/her practice school, using the current textbook. Each reflected on his/her teaching practice by writing an individual report. During a final workshop, these reports were discussed.

This paper describes the development of PCK in the domain of models and modeling among the preservice chemistry teachers in the course of the program outlined above. In particular, the following research question is addressed: What development of the preservice teachers' PCK can be identified and what is the influence of specific factors (i.e., teaching experience, institutional workshops and the mentor) on this development?

Design and procedure

The subjects in the study were a group of twelve preservice teachers of chemistry. Before entering the one-year post-graduate teacher education program, all participants had obtained a Master's degree in chemistry. Four preservice teachers were female, eight were male. All of them had little or no teaching experience. Eight preservice teachers followed the institutional program at Utrecht University, while the other four participated in the program at Leiden University. The programs were taught by two different teacher trainers, the second author of this paper being the Utrecht instructor. The instructor at Leiden University met regularly with the first author, to discuss the design and the progress of the program. It was decided early on to follow a similar approach with respect to models and modeling, that is, the module outlined above was taught in the same manner at both universities. Workshop sessions devoted to models and modeling were led by the respective teacher trainers, the second author of this paper leading the Utrecht sessions. Identical procedures and written

instructions for the teacher trainers were used to guarantee that workshop sessions took place in a similar manner.

A qualitative in-depth study was designed. In order to monitor the development of PCK, we chose a multi-method approach (Baxter & Lederman, 1999). Data were collected at specific moments during the teacher education program (1999/2000). These moments were closely associated with the design of the course module on teaching and learning of models and modeling:

- Firstly, the written responses of all preservice teachers to the two written questionnaires were collected (see Appendices 1 and 2). These questionnaires served as a baseline measurement of their subject matter knowledge and pedagogical content knowledge with respect to models and modeling. Although at this time, the preservice teachers had only limited teaching experience, we wanted to investigate to what extent they had already developed PCK and preconceptions about models and modeling, for instance, on the basis of earlier experiences as a learner of chemistry (e.g., in secondary school), or due to their teaching experiences so far. In addition, the workshop session during which the answers to these questionnaires were plenary discussed were audio taped and transcribed verbatim.
- Secondly, the written responses of all preservice teachers to the questions about the two selected fragments from the research literature (Van Driel & Verloop, 1999 and Grosslight et al., 1991; see above) were collected (see Appendix 3). Again, the workshop session during which these answers were plenary discussed were audio taped and transcribed verbatim.
- Thirdly, the written notes of all preservice teachers with respect to the analysis of a chapter from a chemistry textbook for Grade 9 were collected. These notes included expectations regarding the students' conceptual difficulties as well as difficulties they expected to come across during classroom teaching, and intentions aimed at overcoming

such difficulties (see Appendix 4). The workshop during which these ideas were discussed was again audio taped and transcribed verbatim.

- The lessons preservice teachers taught about a self-chosen topic from the chemistry curriculum with an emphasis on models and modeling (see above) were audio taped by the preservice teachers themselves (see Appendix 5). The reflective reports each preservice teacher wrote about these lessons were collected. A workshop session during which these reports were presented and discussed was recorded on audio tape and transcribed verbatim.
- Finally, the preservice teachers responded to the questionnaire about models and modeling for a second time (see Appendix 1). In addition, they answered a series of questions about the influence of specific activities on their ideas about teaching about models and modeling (see Appendix 6).

In sum, the research data were collected from the preservice teachers' written answers to the questionnaires, from their notes and reports, and from the transcriptions of audio taped discussions during workshops and classroom activities.

We analyzed the data from an interpretative phenomenological perspective. Smith (1995) characterized this view on qualitative analysis as follows: "While one is attempting to capture and do justice to the meanings of the respondent, to learn about his or her mental and social world, those meanings are not transparently available, they must be obtained through a sustained engagement with the text and a process of interpretation" (p.18). Accordingly, the analysis of all data (both written and verbal) focused on the identification of regularities or patterns in the statements made by the respondents, without the use of an a priori established system of categories or codes. Instead, we developed categories on the basis of the data, through an iterative process during which the data were constantly compared with each other,

as well as with theoretical notions, in particular, concerning the nature of PCK (cf., Denzin, 1994).

As this paper focuses on the development of PCK, the analysis of data concerned the following data sources:

1. The written responses to the questionnaire about learning difficulties with respect to models and modeling (see Appendix 2);
2. The written responses to the question about teaching activities the preservice teachers would want to use to bring their students from the lowest level of understanding (see Grosslight et al., 1991) to a higher level (see Appendix 3, Question 5);
3. The individual reflective reports about experiences during teaching practice, focusing on (a) conceptions, types of reasoning, and difficulties of students, and (b) difficulties experienced during teaching and possible changes in a following teaching situation (see Appendix 5);
4. The written responses to the questions about factors and activities influencing the preservice teachers' ideas about teaching about models and modeling (see Appendix 6).

The procedure we followed during the analysis of the data started with comparing the pre- and post-teaching responses of each individual preservice teacher with respect to learning difficulties as well as teaching activities about models and modeling. That is, the reflective reports (3.) of each individual teacher were analyzed with a focus on these issues, and then compared with the responses of the same teacher to Appendices 2 and 3 (Question 5). By comparing and discussing our individual analyses (investigator triangulation; Janesick, 1994), several categories were identified which were used to label each teacher's responses. We then produced an overview of the pre- and post-teaching responses of the preservice teachers. In addition, the transcripts of the workshop sessions and the lessons at school were analyzed, mainly to clarify and check the statements written by the preservice teachers (data

triangulation; Janesick, 1994). Finally, we analyzed the results concerning factors influencing the changes in the preservice teachers' PCK (Appendix 6).

The multi-method approach described above is inherently time-consuming and labor-intensive. In our view, an approach like this is necessary given the complex nature of PCK as a construct, plus our desire to capture the development of PCK. According to Baxter and Lederman (1999), PCK is hard to assess because it is constituted by "what a teacher knows, what a teacher does, and the reasons for the teacher's actions" (Baxter & Lederman, 1999, p. 158).

Results

In this section the results of the study will be described in three parts. First, the changes in the preservice teachers' knowledge of difficulties associated with the learning of models and modeling will be described. Next, changes in the preservice teachers' knowledge of teaching activities aimed at promoting students' understanding of models and modeling will be addressed. Taken together, these changes reflect the changes that occurred in the preservice teachers' PCK. Finally, factors influencing the observed changes will be addressed.

Changes in the preservice teachers' knowledge of difficulties associated with the learning of models and modeling

Several categories were developed which were used to label the pre- and post-teaching responses of the preservice teachers. In Table 1, an overview is presented of the labels we used to describe the changes in the preservice teachers' knowledge of difficulties associated with the learning of models and modeling.

[Insert Table 1 somewhere about here]

From this table, it can be seen that the pre-teaching responses consisted of only one category for eleven preservice teachers, whereas one preservice teacher was not able to mention any student learning difficulty. In the post-teaching responses, which were included in their reflective reports, all but one preservice teacher described learning difficulties in one or more category. One preservice teacher's responses were labeled in three categories; two preservice teachers' responses fell into two categories. Moreover, ten preservice teachers used specific examples to illustrate the learning difficulties they had observed. In general, the preservice teachers' post-teaching responses were more explicit, more detailed, and more precise than their pre-teaching responses. Obviously, the preservice teachers' responses were related to the topic they had focused on during teaching practice. For instance, Clive described in great detail the conceptions of some his students about the relationship between molecular structure and the boiling point of the corresponding substance. Also, he suggested explanations for these conceptions, such as "because the students had used 3D models, they were able to compare the properties of the molecules." As another example, Jack gave a detailed description of a discussion between two of his students about a molecular explanation for the vaporization of water. One student reasoned that during vaporization, water molecules would fall apart in separate hydrogen and oxygen atoms, whereas the other student argued that the water molecules would remain intact.

In their reflective reports, the preservice teachers also described learning difficulties and types of reasoning of students in other domains than models and modeling. Some of these difficulties were directly related to the topic they had been teaching, such as problems students appeared to have with the notion of 'significancy' (Mike), or with concepts and

conventions in the area of electrochemistry (e.g., the notation of cell diagrams or the question which electrode is positive and which one negative; Audrey). In other cases, preservice teachers described learning difficulties of a more general nature, for instance, the observation that students tend to forget knowledge if it doesn't have strong relations to other elements of their knowledge base ("isolated knowledge"; Jack) or the limited ability of students to precisely describe their observations during experiments (Audrey). Finally, one preservice teacher, Holly, addressed the affective aspects of the use of models during her teaching. She had noticed that her students were challenged when they had to solve certain problems using 3D models of molecules, and that they reacted surprised when balloons were used to model hybrids of sp^1, sp^2 and sp^3 types. Holly had not expected these responses of her students.

Changes in the preservice teachers' knowledge of teaching activities aimed at promoting students' understanding of models and modeling

Pre- and post-teaching responses with respect to teaching activities aimed at promoting students' understanding of models and modeling are summarized in Table 2. In this table, pre-teaching responses refer to teaching activities the preservice teachers suggested to use with the purpose to bring their students from the lowest level of understanding (see Grosslight et al., 1991) to a higher level. Post-teaching responses, on the other hand, refer to activities the preservice teachers described in their reflective reports (Appendix 5), and discussed during the final workshop session.

[Insert Table 2 somewhere about here]

In their reflective reports, some preservice teachers presented rich and detailed descriptions of the events that had occurred in their classrooms, addressing both their own

actions as well as the responses of the students. They described what was successful, but also what went wrong, or the problems they encountered. For instance, John chose to focus on the introduction of the atomic model of Rutherford (Grade 9). In his reflective report, he described his approach which started with a description of the historic experiments of Rutherford (exposing a gold foil to a beam of helium particles). When discussing the model of the atom as consisting of a nucleus and, at a large distance, electrons moving around this nucleus, John noticed specific misconceptions among his students, such as the idea that 'air' would fill the space between the nucleus and the electrons. Despite several attempts to convince his students of different ideas, John observed that some students kept believing that 'empty space' would have to be filled with air. In one of his attempts, John used a metaphor, comparing the nucleus of an atom with a football, and then calculating the distance of the electrons to the nucleus to correspond with 750 meters away from the football. To improve his students' understanding of the nature and the development of models in a more general sense, John also presented an overview of several historical models through the ages, starting with Aristotle's model of all matter being composed of the four elements, earth, water, air and fire, and then proceeding via various intermediate models to Rutherford's model of the atom. As another example, Holly had taught several lessons about molecular structures of organic compounds, using 3D stick-and-ball models (Grade 10). Working in groups, the students had to construct models of several molecules. Holly tried to challenge her students by formulating intriguing problems, such as "Find out if it is possible to construct a cyclic molecule including a triple bond using all the carbon atoms you have." She observed that her students initially had difficulties solving this type of problems, but with some assistance of her, they became very enthusiastic. Holly concluded that the use of these models can be very useful and rewarding, but it requires "hard work" from the side of the teacher.

In their reflective reports, some preservice teachers formulated specific intentions for the next time they would be teaching the same topic. These teaching intentions, in particular, can be interpreted as indications of what has been learnt, that is, as growth of the preservice teachers' PCK. For example, Joyce concluded for the next time: "I think I need to pay more attention to the relation between the 'micro' and the 'macro' level. For every topic I am going to teach, such as boiling point and solubility, I want to try to present both aspects to the students." As another example, Jack concluded that in the future he would "try to visualize as many concepts as possible using models and audiovisual aids", adding that he would also "have the students to construct schemes to clarify the structure of a topic."

Other preservice teachers, however, described their teaching approach in rather global terms, or focused on more general aspects of teaching. For instance, Rod had observed differences between the time his students needed to understand specific issues (i.e., balancing reaction equations; Grade 9). This inspired him to think about possible causes for these differences, and about how to anticipate on these differences as a teacher. With respect to the specific topic he had taught, he concluded: "Maybe I should not use models in my explanations the next time I teach this topic. These models may distract the students from the ultimate goal, that is, balancing reaction equations." Mike, who had taught about the concept of the mole (Grade 10), concluded that in order to teach complex concepts like this adequately, it is necessary to understand the content thoroughly: "It is not enough that I understand it myself. To be able to explain it, I need to have a very clear picture of the content." Also, Mike concluded that it was not effective to use long monologues during teaching: "It would be better to talk for example for 10 minutes, and than have the students working on problems for 10 minutes, followed by a plenary discussion of these problems, and so on."

Although it was an explicit element of the assignment (see Appendix 5, 4th element), four preservice teachers did not describe their teaching experiences in their reflective report. The reasons for this omission were different. Clive, Jim and Paul had limited themselves to analyzing students' learning difficulties, using interviews, responses of students to specific test questions, and a questionnaire, respectively. Wayne, on the other hand, mentioned that his lessons had suffered from problems related to classroom management. Referring to the audio recordings he had made of his lessons, he suggested: "These recordings are probably more useful in a study of the classroom management problems of beginning teachers."

Factors influencing the changes in the preservice teachers' knowledge

In the final assignment, the preservice teachers answered a series of questions about the influence of specific activities on their ideas about teaching about models and modeling (see Appendix 6). From the analysis of their responses to these questions, these activities could be ranked in terms of their perceived impact. Experiences during classroom teaching appeared to have been the most influential activity, followed by the discussion during a workshop session about these experiences. The study of articles, and the use of these articles when analyzing a chemistry text book, were considered the next most important activity. Discussions with the mentor at school, however, had not been influential, or only marginally influential, according to all preservice teachers. Finally, three preservice teachers mentioned that working on their reflective reports had had a major impact on their ideas about teaching about models and modeling. Below, these findings are discussed in more detail.

Experiences during classroom teaching

The preservice teachers had all taught a series of lessons with a specific focus on models and modeling. Not surprisingly, they considered their experiences during these lessons

as the most important factor influencing their ideas about teaching about models and modeling. In their explanations, some of them mentioned the usefulness of models they had experienced when trying to clarify the content of specific topics for the students.

Discussion during workshop session about teaching experiences

For three preservice teachers, this discussion had been the most influential activity. Audrey explained that this discussion had made it clear for her that students, unlike chemists, often had great difficulties relating models and reality, and vice versa. Wayne described the impact of this activity as the most powerful confrontation with the realities of classroom teaching. Finally, one preservice teacher had discovered new relationships between 'macro' and 'micro' chemistry as a result of this discussion.

Study of articles, and the use of these articles when analyzing a chemistry text book

In their explanations of the impact of this activity, preservice teachers pointed at the contribution of these articles, in general, to their awareness of the importance of models in science and science education, and more in particular, of the usefulness of the characteristics of models, described in the article of Van Driel and Verloop (1999). However, Wayne indicated he had not yet been able to apply this understanding during teaching. Mike considered this activity as the most influential one for him, explaining that it had made him think about the goal of a model, why it is used, and what aspects of reality it represents.

Discussions with mentor at school

For none of the preservice teachers, discussions with their mentor at school about the teaching and learning of models and modeling had been an important factor. It must be noted however, that the mentors were not instructed specifically about this issue by the university-

based educators. Thus, the preservice teachers themselves were expected to bring up models and modeling in discussions with their mentor. Four of them explicitly stated they had not had such discussions. Only two preservice teachers mentioned that such discussions had occurred. One of them, Rod, explained that he and his mentor had discussed a problem both of them had experienced when they tried to explain a specific model.

Working on the reflective reports

For three preservice teachers, working on their reflective reports had been one of the most influential activities. Audrey explained that, in particular, analyzing and reflecting on her teaching experiences had helped her to understand specific learning difficulties of her students. In addition to teaching lessons focusing on models and modeling, Clive and Jack both had interviewed some of their students. They described the results of these interviews in their reports. Jack stated that listening to his students, and analyzing their statements, had helped him to understand the pitfalls some models have for students, like the different meanings the sticks can have in a 'stick-and-ball' model of a molecule. As an experienced chemist, he had been unaware of these pitfalls. Clive reasoned in a similar way, stating that the interviews had allowed him to focus on his students' ways of thinking. He explained that, on the basis of his improved understanding of his students' thinking, he expected to be able to teach more effectively.

Conclusions and discussion

Most of the preservice teachers in this study displayed a distinct development of PCK about models and modeling. The PCK developed by the preservice teachers may be summarized as follows. In the first place, they apparently became more aware of the role of

models and modeling in the teaching of chemistry. In this respect, the use of selected fragments from the educational literature, followed by the analysis of a text book, appears to have been successful. Secondly, they obtained a better understanding of specific difficulties connected with the learning of particular models or modeling activities. Finally, most of them presented evidence of an increased knowledge of the use of specific teaching activities in the domain of models and models. The two latter results were apparently mostly influenced by the preservice teachers' experiences during the teaching of a series of lessons, which focused on models and modeling, followed by writing a reflective report about these lessons and discussing these reports during a final workshop session.

Obviously, these conclusions are stated in very general terms. As became apparent in the previous section, the specific PCK the preservice teachers developed in the course of the module on teaching models and modeling differed substantially. These differences are related to the fact that the preservice teachers had taught about different topics. As PCK refers to particular topics, this finding is consistent with our conceptualization of PCK (Van Driel et al., 1998). Another explanation for the differences in PCK development concerns the observation that the preservice teachers differed in their focus of attention. Whereas some of them indeed focused on models and modeling as a central element in chemistry teaching, others apparently were more concerned about the content of the topic they had been teaching (e.g., Mike about the mole and the notion of significancy, and Audrey about concepts and conventions in the area of electrochemistry). Finally, some preservice teachers' concerns focused on general issues of teaching (Wayne; classroom management) or were not very clear at all (Paul).

In some cases, a discrepancy was observed between the preservice teachers pre- and post-teaching responses. That is, the preservice teachers sometimes suggested teaching approaches in their pre-teaching responses, which they did not apply during classroom

practice. For instance, Jack had suggested to address the historical development of models of the atom to improve students' understanding of models and modeling. In practice, however, he focused on the use of visualizations to explain processes at a molecular scale. Possibly, this discrepancy is related to the specific topic Jack had taught (i.e., processes taking place when sugar or salt are dissolved in water; Grade 11). Anyway, it is not possible to assess this discrepancy in terms of a change in PCK. Other cases where such discrepancies were observed concern Joyce and Audrey. The former had suggested to use various models highlighting different aspects of the same target, but she apparently did not apply this strategy when she taught about hydrogen bonding to explain differences in boiling point and solubility in Grade 10. The latter had initially indicated to explicitly address the limitations of specific models, but no evidence of this approach could be found in her reflective report. Obviously, discrepancies between teachers' intentions and the strategies they actually apply in their classrooms are not uncommon in studies of beginning teachers (e.g., Briscoe, 1991).

Some preservice teachers had carried out small scale research activities, such as interviewing a couple of their students (Clive, Jack), or administering a specific test (Paul, Jim). In particular, the analysis of the interviews had contributed substantially to the understanding of students' learning difficulties and ways of reasoning. This result is in accordance with other studies in which teachers explored specific conceptions of their students (cf. Smith, 1999). It is remarkable, however, that the preservice teachers in this study were not given specific instructions about how to interview their students. Thus, the use of interviews may be incorporated in a next version of our module.

A final conclusion concerns the role of mentors in this study. As stated before, we did not instruct the preservice teachers' mentors explicitly about how to supervise and promote their development of PCK about models and modeling. As it turned out, the impact of the mentors on this development had been marginal. However, it has been reported in the

literature that, under specific conditions, preservice teachers may benefit from studying their mentors' practical knowledge (Zanting et al., 1998). Thus, we could consider to involve the mentors in a more structured and systematic way to stimulate the preservice teachers to inquire and explore their mentors' PCK about models and modeling.

To conclude this paper, we wish to reflect on the instruments we have used in this study to investigate the development of PCK. Not all the instruments we used (see Appendices 1 to 6) proved very useful with respect to the investigation of PCK development. It must be noted, however, that some of these instruments (e.g., Appendices 1 and 3) were designed in the first place to explore the preservice teachers' content knowledge about models and modeling. The results obtained with these instruments will be discussed in a separate paper (De Jong & Van Driel, 2001). The instruments we used in this study were closely related to the assignments we used in the teacher education program (e.g., analyzing a text book, writing a reflective report about a series of lessons). Although the advantage of this 'naturalistic' approach to data collection is obvious (e.g., Van Driel et al., 1998), there are also limitations associated with this approach. In particular, in this study we would have liked to know more precisely what the preservice teachers concluded on the basis of their teaching experiences. For instance, as became clear in the previous section, four out of twelve preservice teachers did not report about their teaching activities. If we had decided to interview them on the basis of their reflective reports, we could have obtained a more complete picture of their PCK. Consequently, the use of interviews is considered for a next cycle of our research project.

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APPENDICES

Appendix 1. Questionnaire about models and modeling

Item 1. A car made of 'Lego'
Item 2. A map of Amsterdam
Item 3. The water cycle (sea water vaporizes, forms clouds, rain falls down, etc.)
Item 4. $[H^+] . [Ac^-] = K_a$
Item 5. Two blue 'marbles' which are connected by sticks with a black 'marble', at an angle of 109^o
Item 6. $Na^+ (aq) + Cl^- (aq)$

Question 1.
A. Note for each item if this concerns a model. Give an explanation.
B. If yes, what is modeled? Give an explanation.

Question 2.
Note your connotations regarding the term model. Use examples to clarify your answer.

Question 3.
How would you describe a model to a person who does not know what a model is?

Question 4.
For what purposes do chemists use models? Use examples to clarify your answer.

Question 5.
Models can be changed. What reasons or 'occasions' could chemists have to change a particular model?

Question 6.
Do you think that chemists can use several models for the same phenomenon or 'object'? Why or why not?

Appendix 2. Questionnaire about teaching and learning about models and modeling

Question 1.
As a student at high school and university, you have learnt about scientific models and their use. What learning difficulties do you remember?

Question 2.
During your preceding classroom teaching, you may have paid attention to models and modeling implicitly or explicitly. What difficulties in teaching and student learning did you notice?

Appendix 3. Questions about the articles by Van Driel and Verloop (1999) and Grosslight et al. (1991)

Given is a picture in a chemistry textbook, which displays space-filling models of molecules of HCl, H_2O, NH_3, CH_4, and CCl_4.

Question 1:
Discuss this type of models from the perspective of the seven characteristics of models in the article by Van Driel and Verloop (1999). Address each characteristic separately.

Question 2:
Describe how students at 'level 1' (Grosslight et al., 1992) will perceive these models. Illustrate your answer with concrete statements or conceptions of students.

Question 3:
The same question for students at 'level 2'.

Question 4:
The same question for students at 'level 2'.

Question 5:
Give some examples of teaching activities which can be used to promote students' understanding from 'level 1' to a higher level.

Appendix 4. Analysis of a chemistry textbook.

Assignment 1:
Read sections 7.1, 7.2 and 7.3 from the textbook *Chemie 3 havo/vwo* (4th edition; 1995). [This is a commonly used textbook in chemical education in Grade 9 in the Netherlands].

Assignment 2:
Write down your answers to the following questions:

Question 1:
Which difficulties do you expect your students will have when studying these sections?
Question 2:
Which difficulties do you expect to encounter when teaching about these sections?
Question 3:
Would you plan to change the design of these sections? Give an explanation

Appendix 5. Teaching a series of lessons focusing on models and modeling.

1. SELECT an appropriate section or chapter from the textbook you will be teaching from in the upcoming period. Your selection should focus on models and modeling.

2. Make AUDIO RECORDINGS of the lessons when you are teaching this selected section or chapter.

3. Let your class make a TEST at the end of these lessons. Make an ANALYSIS OF THE MISTAKES the students have made in this test.

4. Write a concise REPORT (2 to 4 pages) of the most remarkable episodes and events during the lessons, including the analysis of the mistakes made by students in the test. In your report, address the following issues:

    1. Which conceptions and types of reasoning of students did you identify?
    2. What difficulties of students did you identify? Can you name possible causes?
    3. What difficulties did you experience during teaching? Name possible causes.
    4. What changes would you make in these lessons a next time? Please explain.

5. Take your report with you to the next workshop session, together with your audio recordings. Your report will be discussed during this workshop.

Appendix 6. Questions about influences on preservice teachers' ideas about teaching about models and modeling.

Please describe to what extent your ideas about teaching about models and the relation between 'macrochemistry' and 'microchemistry' have been influenced by:

a) The articles we gave you and the use of these when analyzing the chemistry textbook;

b) Experiences during classroom teaching;

c) Discussions with your mentor at school;

d) Discussion during workshop session about your teaching experiences;

e) Other factors, viz.:

Table 1. Preservice teachers' knowledge of difficulties associated with the learning of models and modeling.

Teacher	*Pre-teaching responses* Difficulties of students concern:	*Post-teaching responses* Difficulties of students concern:
Audrey	Problems relating models with reality, e.g., using ionic models to explain results of experiments	Problems to apply a given model in various situations, e.g., electrochemical cells
Jack	Problems with the abstract nature of atomic models	Problems with the abstract nature of atomic models; Confusing models with reality, e.g., the idea that water molecules are 'liquid'
Clive	Unable to relate models with reality, e.g., the model of chemical elements and results of experiments	Problems relating models with reality, e.g., molecular structure and bonding with boiling point
Rod	Problems with the abstract nature of atomic models	Unable to use models to solve specific models, e.g., balancing reaction equations
John	Unable to relate models with reality, e.g., movement of particles and macroscopic temperature	Confusing models with reality, e.g., the idea that the space between nucleus and electrons is filled with 'air'
Wayne	Problems with the abstract nature of atomic models	Problems relating models with visible phenomena, e.g., the model of colliding particles with the rate of a reaction
Mike	Problems with the abstract nature of atomic models	Problems with the abstract nature of models, e.g., the number of particles in a mole
Holly	Problems relating models with reality, e.g., using ionic models to explain precipitation reactions	Problems relating models with reality, e.g., molecular structures with macroscopic properties of substances
Paul	-	[Investigated students' responses to statements about molecules, but gave no analysis]
Rita	Problems relating models with reality, e.g., molecules and atoms with substances	Problems relating (microscopic) models with the macroscopic world, and vice versa; Problems to comprehend the size of atoms; Problems to interpret chemical formulae
Jim	Problems with the abstract nature of atomic models	Problems with the abstract nature of atomic models
Joyce	Problems relating models with reality, e.g., molecules with macroscopic properties of substances	Problems with the abstract nature of models of chemical bonding; Problems relating models with reality, e.g., molecular structure with solubility and boiling point

Table 2. Preservice teachers' knowledge of teaching activities aimed at promoting students' understanding of models and modeling.

Teacher	*Pre-teaching responses*	*Post-teaching responses*
Audrey	Addressing limitations of models; Using various models representing the same target, but with a different goal	Using schemes and models to explain relation between models and reality in the context of electrochemical cells
Jack	Using various (molecular) models; Addressing the historical development of models of the atom	Using visualizations and other tools to explain molecular processes; Using schemes, made by students, to clarify the structure of a topic
Clive	Addressing limitations of models; Demonstrating that models are man-made inventions; Pointing at various models representing the same target	-
Rod	-	Using models can be confusing for students when the aim is to understand the balancing of reaction equations
John	Relating models with reality, e.g., molecular structure with boiling point	Using specific questions, discussions and experiments to change students' preconceptions of atomic models; Addressing historical development of models
Wayne	Activities involving the building and analysis of models by the students	-
Mike	Using various (molecular) models; Activities involving the building of models by the students	Using examples from daily life to explain abstract concepts, e.g., the mole; Using models as a bridge between the world of particles and phenomena
Holly	Activities involving the building of models by the students	Using 3D models of molecules to improve understanding of isomerism and chemical bonding
Paul	Discussing various models; Addressing the historical development of certain models	-
Rita	-	Using various models, in particular, to improve understanding of distinction between 'atom' and 'molecule'
Jim	Explicitly relating models and reality, e.g., molecular structure with macroscopic substances; Elaborating models in computer simulations	-
Joyce	Explaining the goal of a certain model; Demonstrating various models representing the same target, but explaining different aspects	Emphasize the relationship between models and reality; Address this relationship explicitly with each new topic